

Ocean biogeochemistry in the Earth system modeling framework: applications and approach

Matthew C. Long

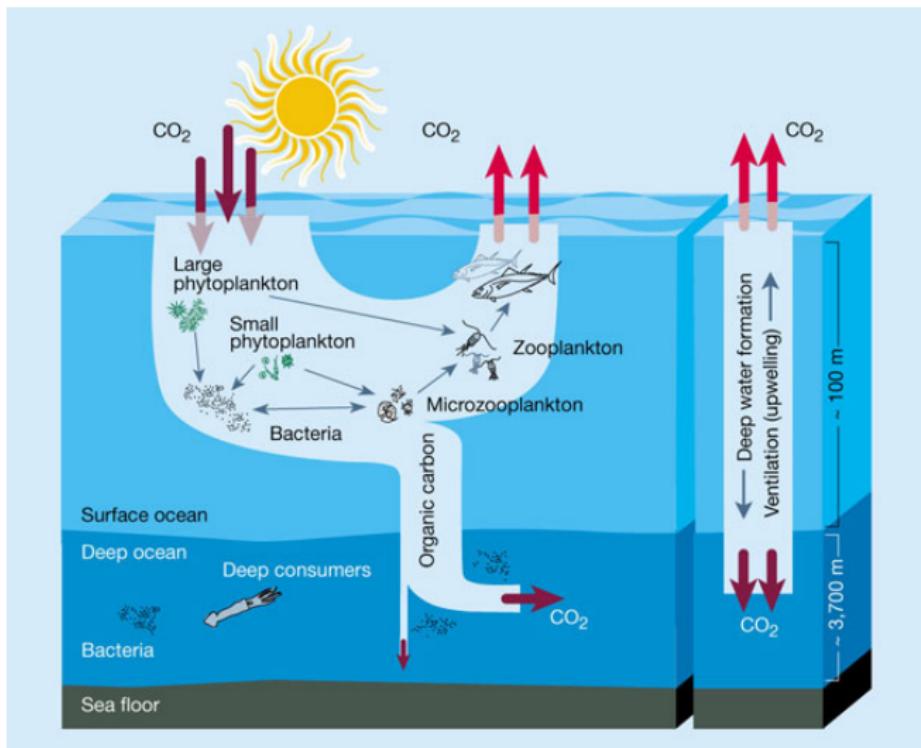
Climate and Global Dynamics Laboratory
National Center for Atmospheric Research

8 June 2016

DOE ESM Meeting

Ocean biogeochemistry

The interface between inorganic substrate and living systems



Some example research questions

How does the ocean carbon cycle behave under a changing climate?

How does climate variability impact marine ecosystems?

What is the role of mesoscale eddies in structuring ocean ecosystems?

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Ocean uptake under 1% y^{-1} ramping CO_2

No climate change

ΔC^β Overturning circulation drives anthropogenic carbon uptake.

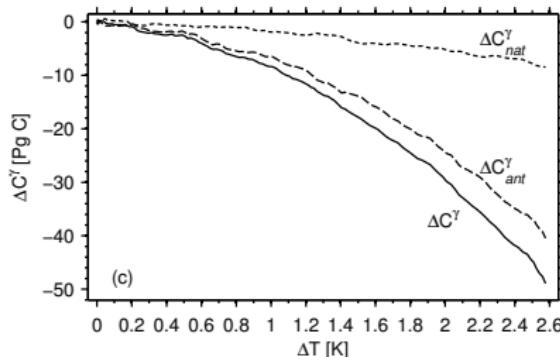
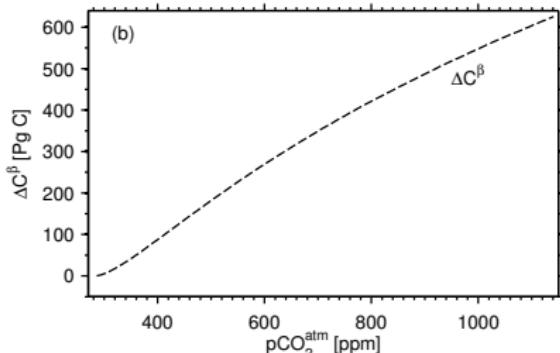
Climate feedback

ΔC_{ant}^γ Buoyancy stratification curtails anthropogenic CO_2 uptake.

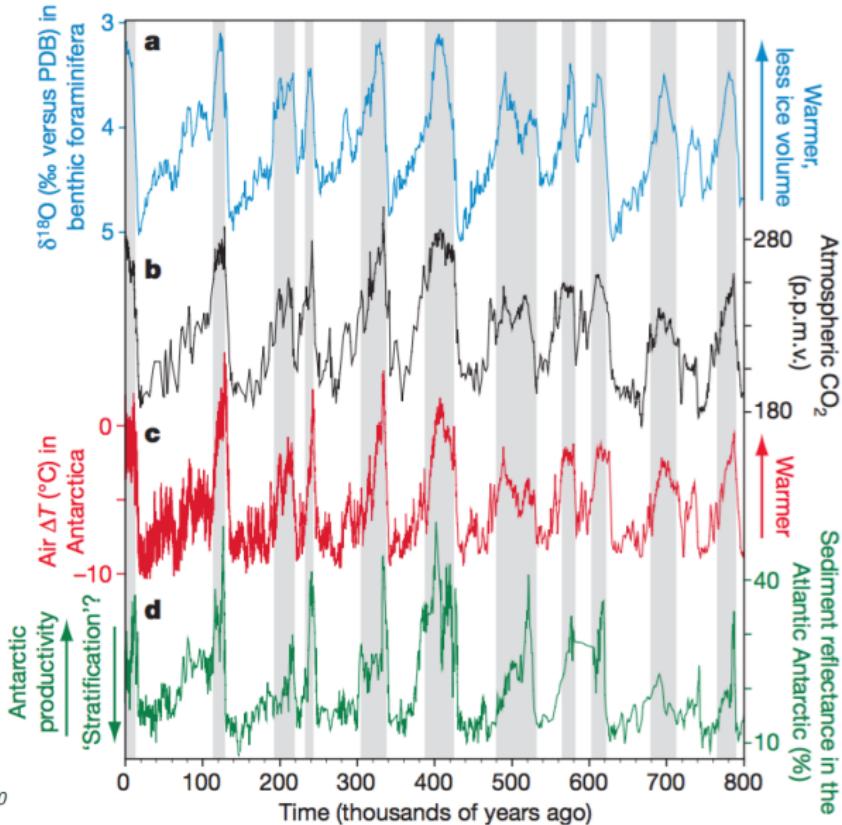
ΔC_{nat}^γ Reductions in biological export production cause release of natural carbon.

$$\Delta C^{ocn} = \Delta C^\beta + \Delta C_{nat}^\gamma + \Delta C_{ant}^\gamma$$

Carbon inventory changes



Ocean ventilation modulates glacial-interglacial CO₂ fluctuations



Sigman et al. 2010

Some example research questions

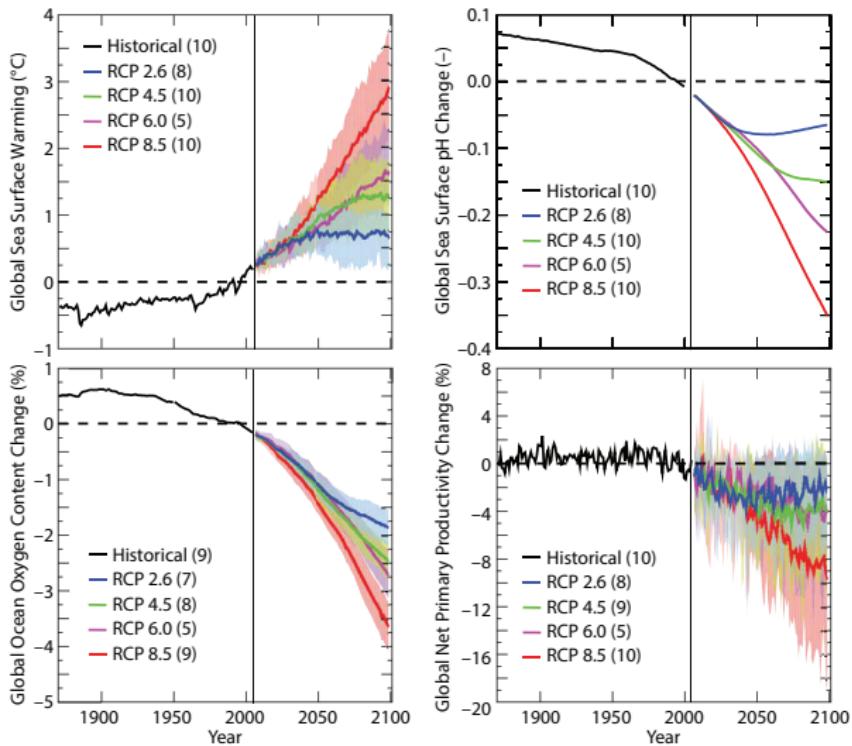
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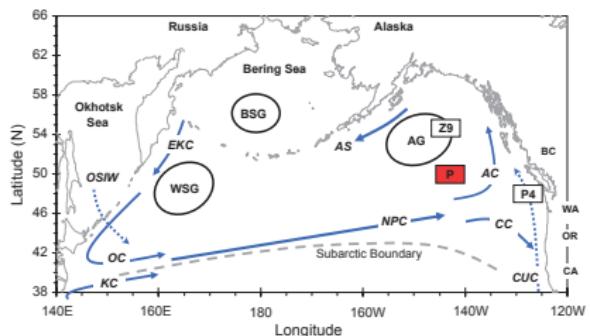
Anthropogenic forcing

CMIP5 projections of global mean quantities

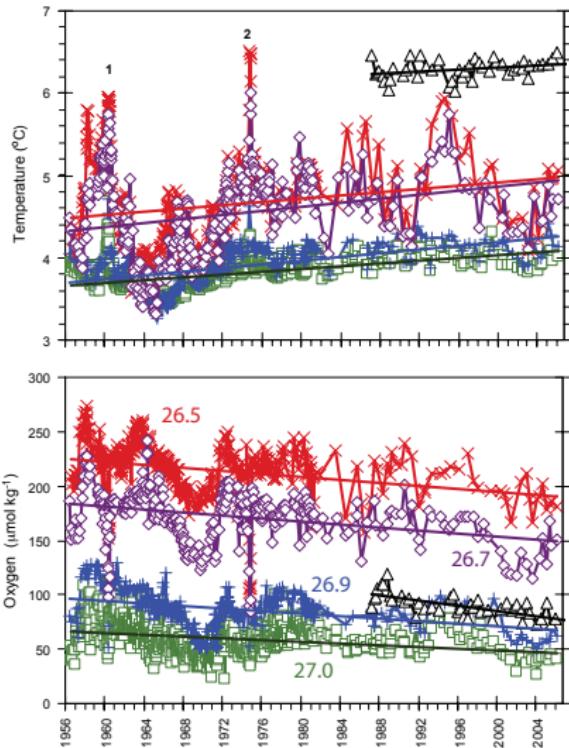


Observed trends in interior $[O_2]$

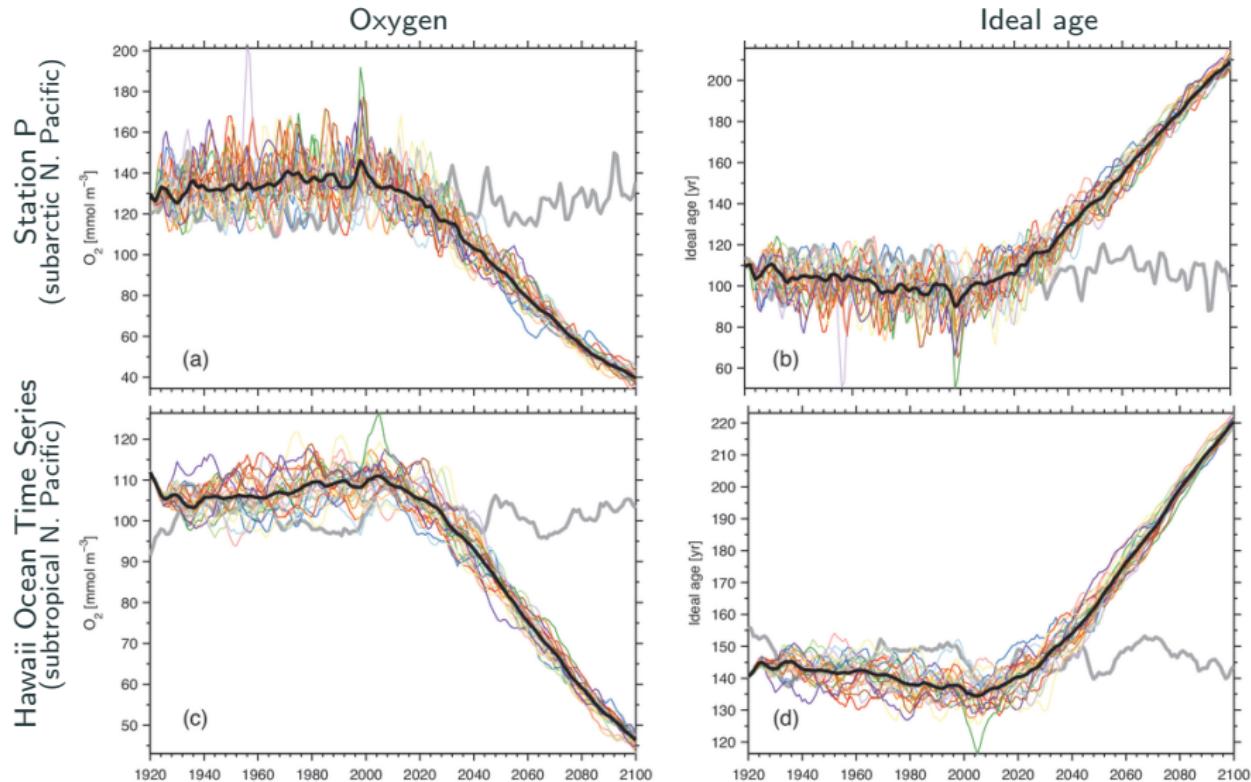
Subarctic North Pacific Ocean Station P: isopycnal surfaces



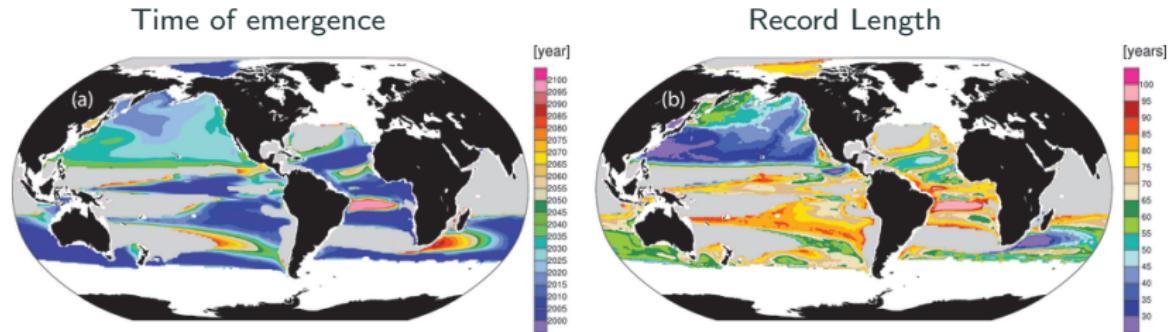
Whitney et al. 2007



Large Ensemble results: ocean timeseries locations



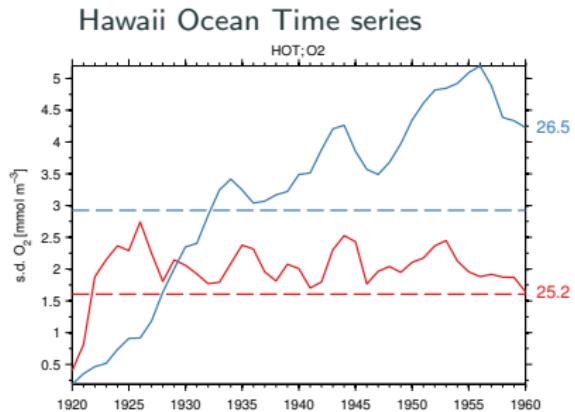
Time of emergence for forced trends



	HOT		Station P	
σ_θ	25.2	26.5	26.5	26.7
ToE (trends)	2017 ± 12.1	2028 ± 5.7	2025 ± 6.8	2027 ± 8.1
Trend length	73 ± 16.6	32 ± 12.8	47 ± 15.9	50 ± 19.5

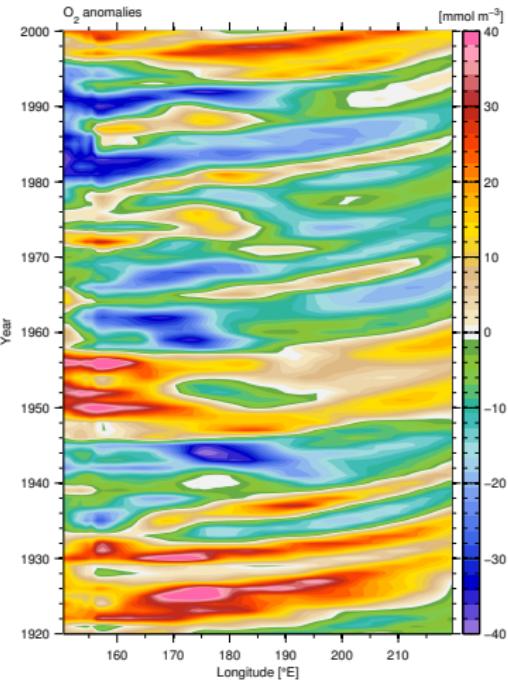
Initial value prediction timescales

Forecast distribution spread



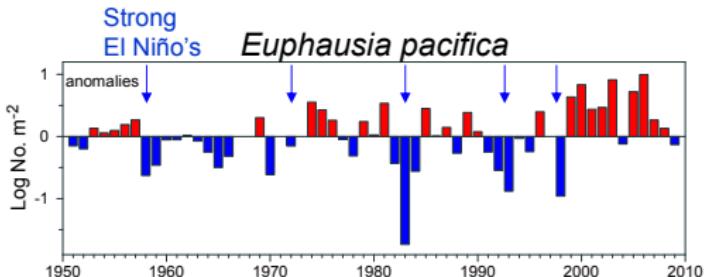
Propagating anomalies

Subpolar North Pacific (45-50°N)



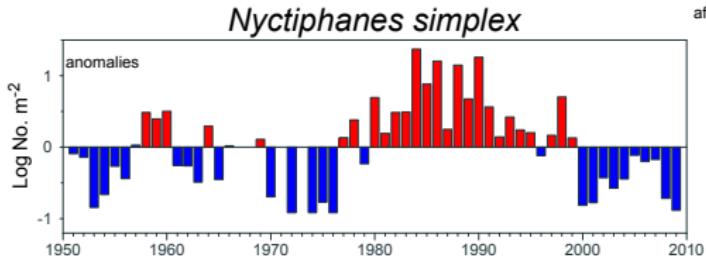
Ecosystem response timescales in California Current System

Interannual variability



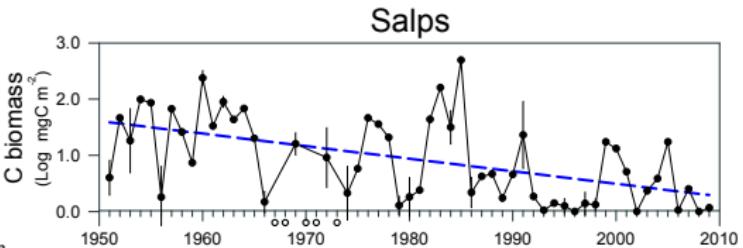
after Brinton & Townsend 2003
(updated, M.Ohman)

Decadal variability



krill

Secular trends



courtesy of M. Ohman



photo: D.Wrobel

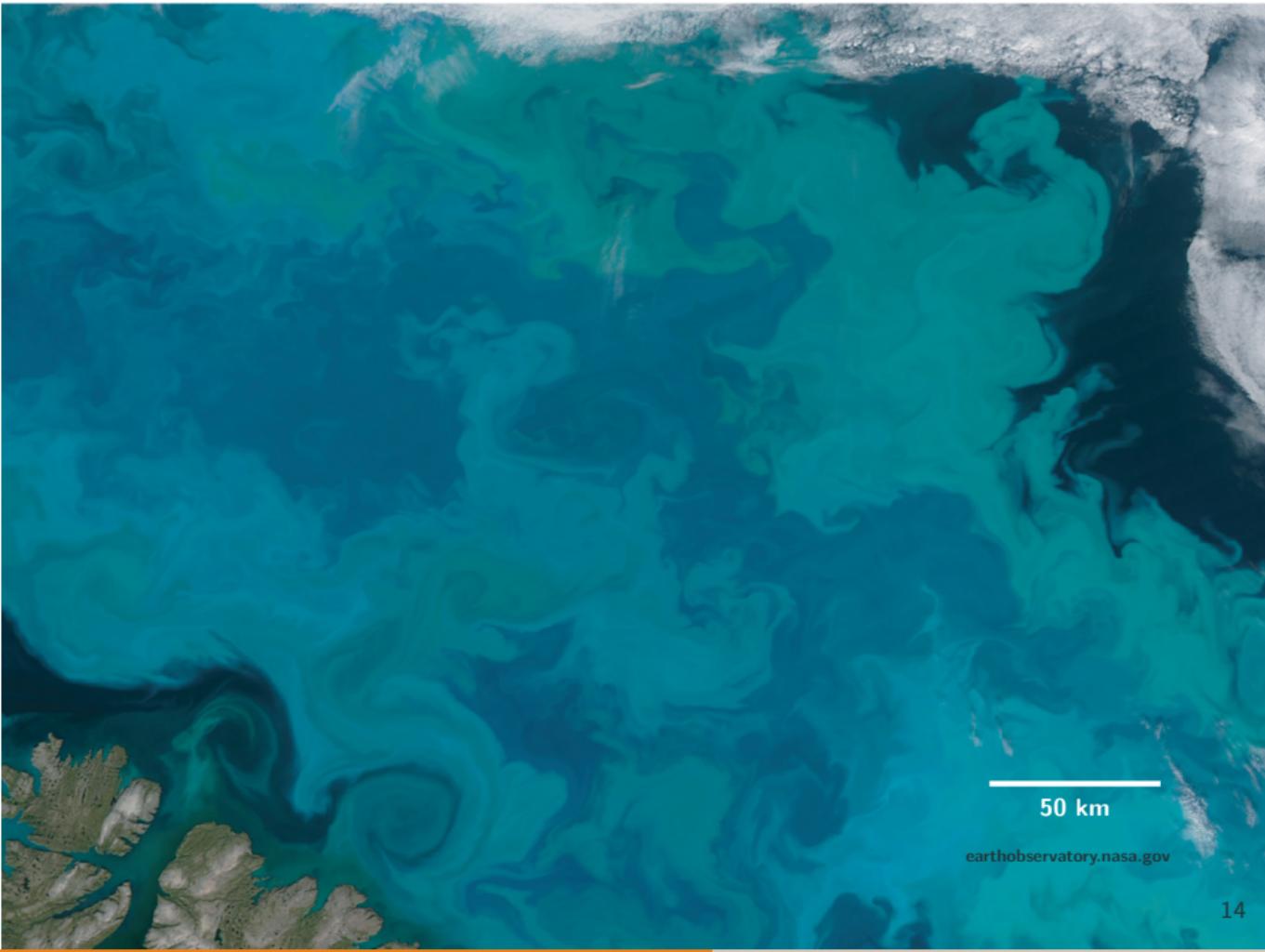
Lavaniegos & Ohman 2007
(updated)

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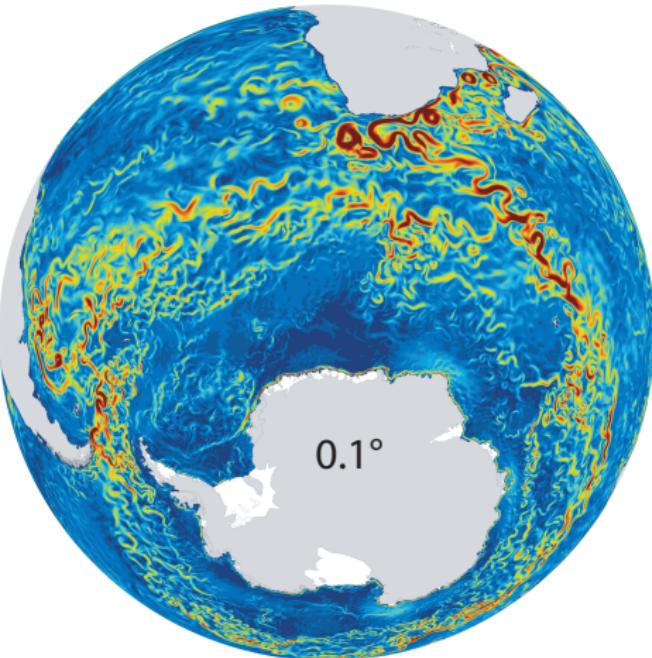
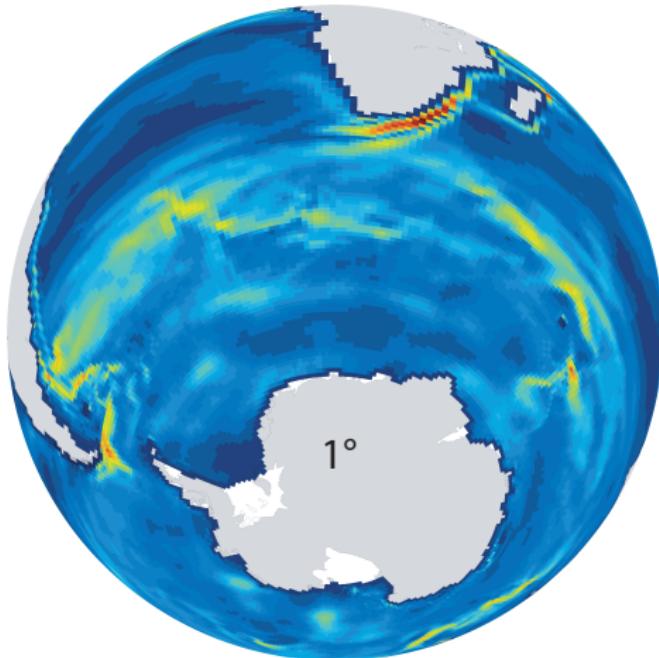


50 km

earthobservatory.nasa.gov

Structure of physical perturbations: Sluggish versus energetic oceans

Kinetic energy

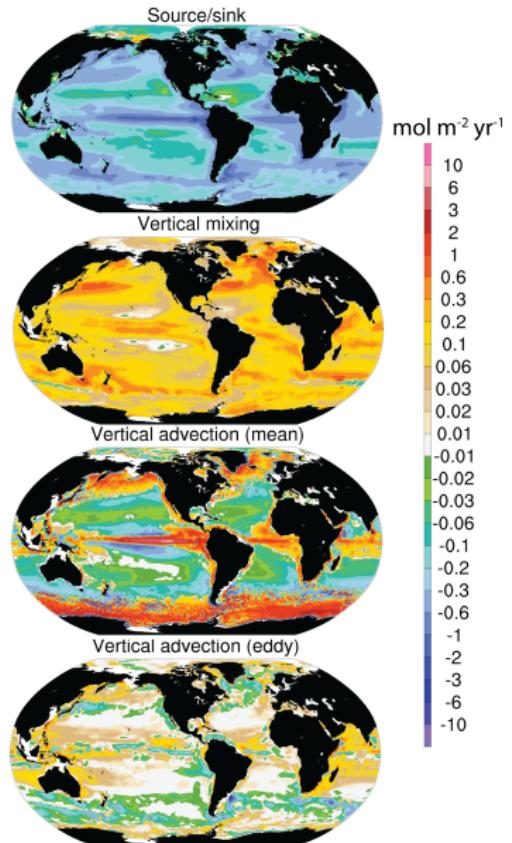


The role of eddies in sustaining ocean productivity

Upper ocean nitrate budget

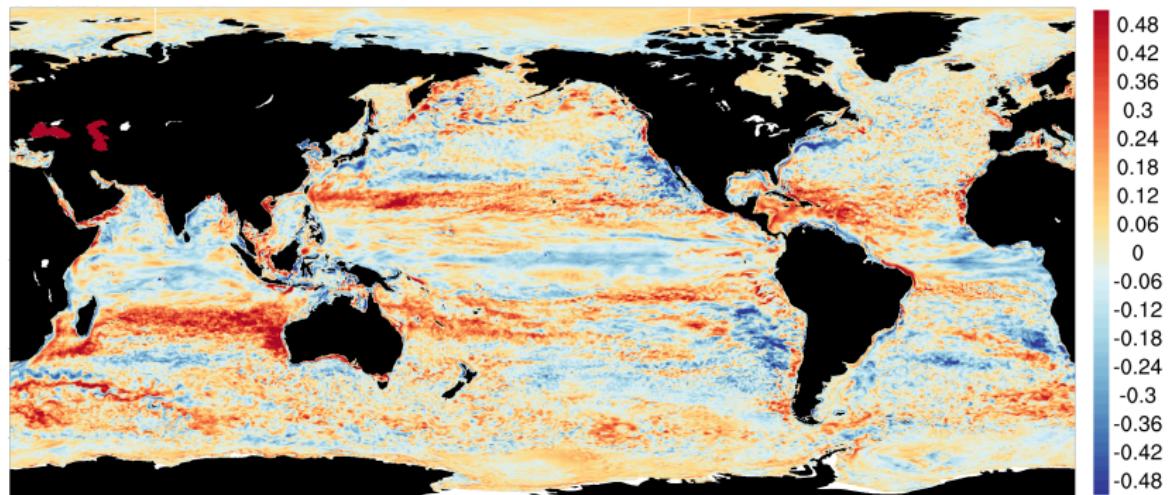
$$\frac{\partial \overline{N}}{\partial t} + \nabla \cdot (\bar{\mathbf{u}} \overline{N}) + \nabla \cdot (\overline{\mathbf{u}' N'}) - \frac{\partial}{\partial z} \left(k_v \frac{\partial N}{\partial z} \right) = \overline{J_N(x)}$$

Long et al., in prep



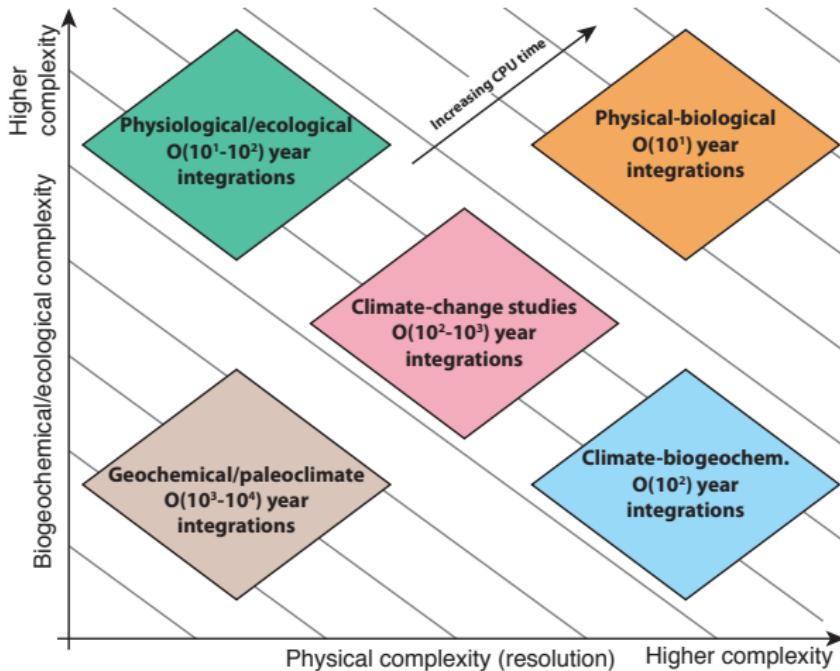
Eddy-induced perturbations of upper ocean habitat

Cross correlation of anomalies in surface chlorophyll and SSH



Long et al., in prep

Computational cost is a fundamental constraint



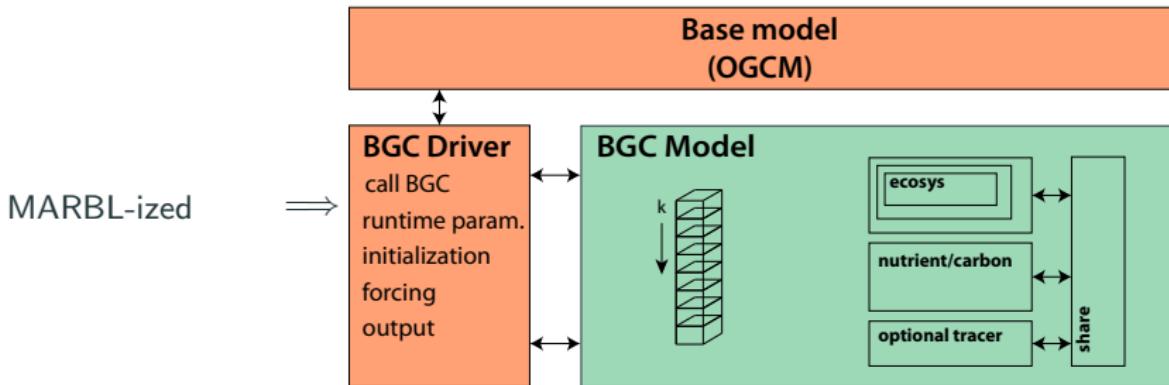
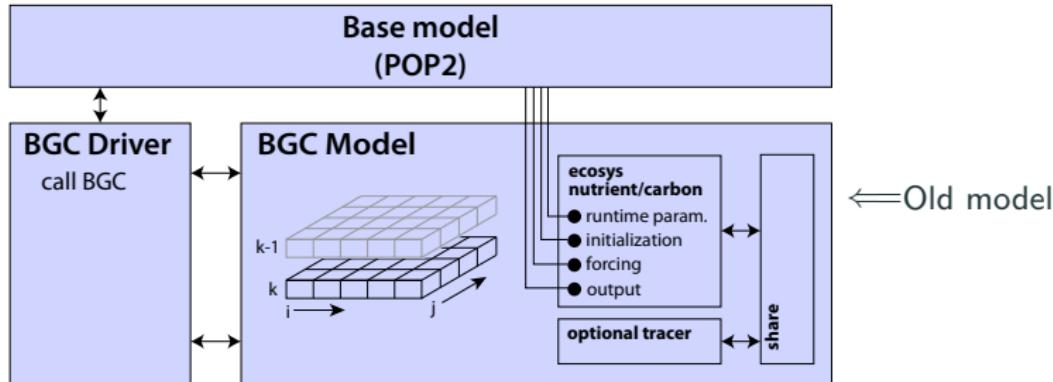
MARBL Marine Biogeochemistry Library



Objectives

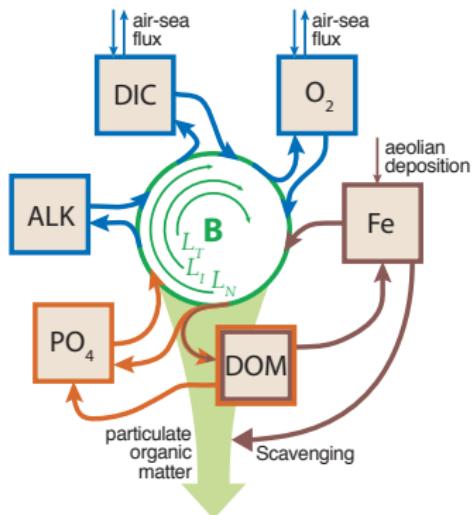
1. Enable portability to alternate physical frameworks.
2. Enable question-dependent configuration.
3. Improve physiological and ecological realism.

$$\frac{\partial \chi}{\partial t} + \nabla \cdot (\mathbf{u}\chi) - \nabla \cdot (K \cdot \nabla \chi) = \underbrace{B_\chi(\mathbf{x})}_{\text{MARBL}}$$

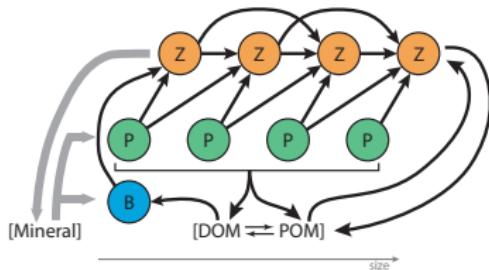


Model complexity, from biogeochemical to ecological

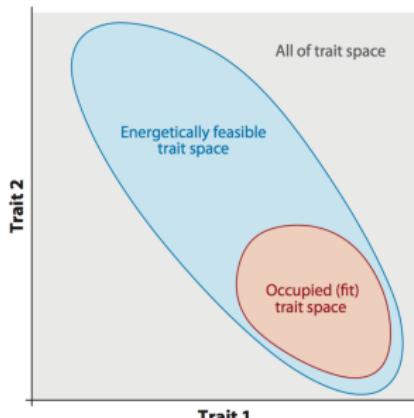
Implicit biomass treatment



Planktonic food webs

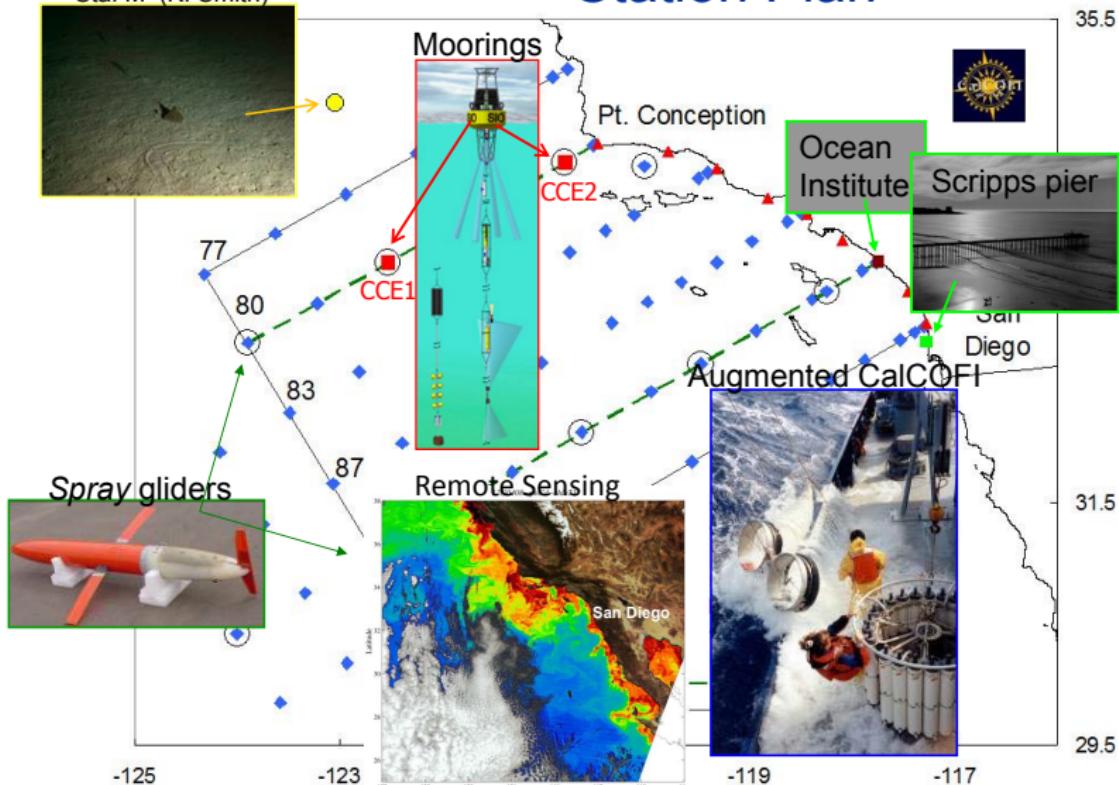


Trait-based approaches



California Current Ecosystem LTER observational network

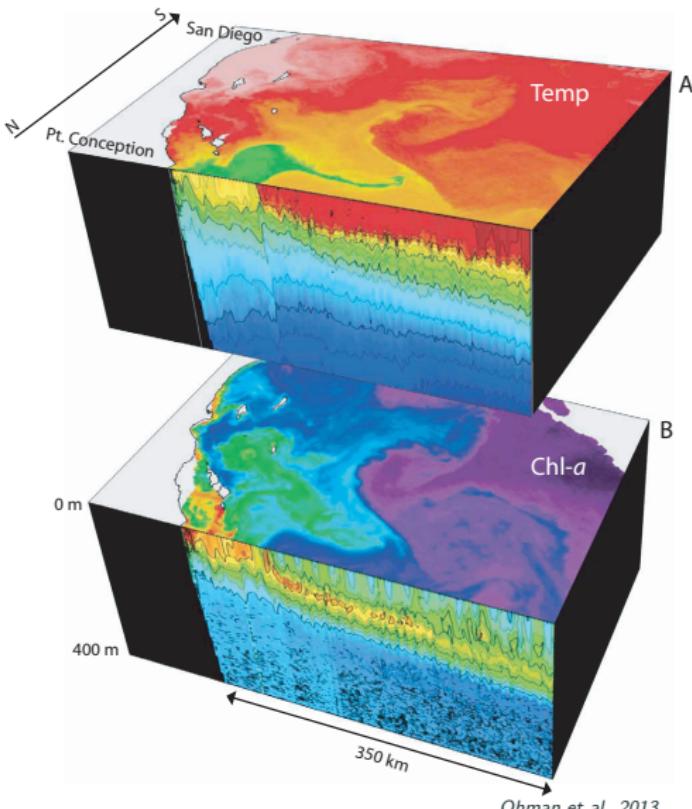
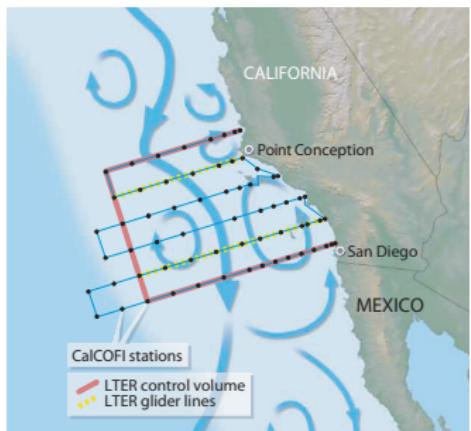
Benthic time series
Sta. M (K. Smith)



courtesy of M. Ohman

Observations tend to be sparse, but there are intensive pockets

LTER & CalCOFI stations



MARBL: key deliverables

1. Standalone-library implementation of ocean biogeochemistry;
2. Implement MARBL in POP and MPAS-O;
3. MPAS-MARBL simulations of California Current system
(partnership with CCE-LTER group).

Summary: ocean biogeochemistry in the Earth system

Support and conduct research that seeks to:

1. Enhance fundamental understanding of the Earth system; and
2. Develop societally-relevant information and tools.

Requirements:

Driving processes operate across a wide range of spatiotemporal scales.

Requirement: Support a stable of scale-specific physical frameworks.

Biogeochemical phenomena emerge from complex interactions.

Requirement: Flexible modeling infrastructure.

Models are hypotheses that must be verified.

Requirement: Strong connections to observational programs.